TITLE OF THE INVENTION

EXPOSURE APPARATUS AND DEVICE MANUFACTURING

METHOD USING THE SAME

5   FIELD OF THE INVENTION

The present invention relates to an exposure

apparatus used in the lithography step of the steps in

manufacturing a device, e.g., a semiconductor device

such as an IC or LSI, a liquid crystal device, an image

10   sensing device such as a CCD, or a magnetic head, and a

device manufacturing method using the exposure

apparatus.

BACKGROUND OF THE INVENTION

15   In a manufacturing process of a semiconductor

integrated circuit, an exposure apparatus is used to

form a pattern on a photosensitive material (to be

referred to as a "resist" hereinafter) on a substrate

(to be referred to as a "wafer" hereinafter). With an

20   increase in the area of recent semiconductor integrated

circuits and an advance in micropatterning, a scanning

exposure apparatus called a step-and-scan exposure

apparatus designed to illuminate part of a pattern on a

mask as a master in the form of a slit, and perform

25   exposure by synchronously scanning the mask and a wafer

at a constant velocity is replacing a conventional

step-and-repeat exposure apparatus, a so-called stepper,

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which is designed for cell projection of a mask pattern.

In general, a proper exposure amount (to be referred to as a "set exposure amount" hereinafter) D (J/m^2) for the formation of a proper mask pattern image is set for a resist. A scanning velocity V (mm/sec) in the scanning exposure apparatus must satisfy

$$V \leqq Imax/D \times Wx \qquad \ldots (1)$$

where Imax (W/m^2) is the maximum exposure illuminance of exposure light on a wafer, and Ws (mm) is the exposure slit width on the wafer in a non-scanning direction.

According to inequality (1), the maximum scanning velocity controlled by the set exposure amount D is given by

$$Vd = Imax/D \times Ws \qquad \ldots (2)$$

A maximum scanning velocity Vmax determined from the performance of a stage control system, including structural/mechanical performance, is substantially determined in the scanning exposure apparatus, and the scanning velocity V must satisfy

$$V \leqq Vmax \qquad \ldots (3)$$

One of the factors responsible for the above requirement is that the positions of a mask and wafer cannot be properly controlled to result in a deviation (to be referred to as a "synchronization error" hereinafter), i.e., a deviation from a predetermined

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positional relationship between the mask and the wafer, in the scanning exposure apparatus designed to form a mask pattern on the wafer by scanning/exposing the mask and wafer while performing synchronous control to keep the positions of the mask and wafer in the predetermined positional relationship. This leads to a decrease in the resolution of a resist pattern and a deviation from the proper imaging position of the resist pattern, resulting in a trouble in the manufacture of a semiconductor integrated circuit. This synchronization error is almost proportional to the scanning velocity. As the scanning velocity increases, the synchronization error increases. For this reason, the maximum scanning velocity Vmax that suppresses the synchronization error within an allowable synchronization error range is determined.

If a pulsed light source such as a KrF excimer laser or ArF excimer laser is used as an exposure light source to meet the requirement for micropatterning, since pulsed light varies in energy for each pulse, an integrated exposure amount is made uniform within a desired precision by performing exposure with a plurality of pulsed light beams equal to or larger than a predetermined pulse count (to be referred to as a "minimum exposure pulse count" hereinafter) Pmin. For this reason, in the scanning exposure apparatus, the following inequality must be satisfied:

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$$Pmin \leqq Ws/V \times f \qquad \qquad \ldots(4)$$

where f (Hz) is the oscillation frequency of the
exposure light source laser.

According to inequality, letting fmax be the
5   maximum oscillation frequency of the exposure light
source laser, the maximum scanning velocity controlled
by the minimum exposure pulse count Pmin is given by

$$Vp = Ws/Pmin \times fmax \qquad \qquad \ldots(5)$$

Conventionally, as disclosed in, for example,
10 Japanese Patent Laid-Open Nos. 10-270345 and 10-223513,
a scanning velocity is determined with the oscillation
frequency fmax when a low-sensitivity resist with the
large set exposure amount D is to be used, or a
scanning velocity is determined to set the maximum
15 scanning velocity Vmax when a high-sensitivity resist
with the small set exposure amount D is to be used, so
as to satisfy inequalities (1), (3), and (4).

If the integrated exposure amount can be set to
Pmin regardless of the maximum scanning velocity Vd
20 controlled by the set exposure amount D represented by
equation (2), the maximum scanning velocity Vmax
controlled in accordance with the performance of the
apparatus, and the value of the set exposure amount D,
the minimum value of Vp controlled by the minimum
25 exposure pulse count represented by equation (5) is
determined as a scanning velocity in actual exposure
operation.

An important item in manufacturing a
semiconductor integrated circuit is a reduction in the
size of an integrated circuit pattern. This is mainly
associated with optical imaging performance and the
5   performance of a stage control system, in particular, a
in a scanning exposure apparatus.

In manufacturing a semiconductor integrated
circuit, about 10 to 20 exposure processes are
repeatedly performed for one wafer. As a reduction in
10   integrated circuit pattern size, an increase in overlay
accuracy of integrated circuit patterns between the
respective exposure processes is associated with one of
important abilities.

In the manufacturing process of a semiconductor
15   integrated circuit, another important factor is
productivity. The productivity of an exposure
apparatus increases as the time required to expose one
wafer shortens, i.e., the number of wafers that can be
exposed per unit time (to be referred to as a
20   "throughput" hereinafter) increases.

In a conventional scanning velocity determination
method, exposure is performed at the smallest value of
the maximum scanning velocity Vd controlled by the set
exposure amount D, the maximum scanning velocity Vmax
25   controlled from the performance of the apparatus, and
the maximum scanning velocity Vp controlled by the
minimum exposure pulse count, i.e., the highest

possible scanning velocity of the maximum scanning velocities Vd, Vmax, and Vp.

This indicates that the throughput increases as the scanning velocity increases. Obviously, in a scanning exposure apparatus designed to illuminate a pattern area to be exposed in the form of a slit and perform exposure by synchronously scanning a mask and wafer at a constant velocity, the time required to scan the pattern area to be exposed shortens as the scanning velocity increases while the length of the pattern area to be exposed in the scanning direction remains unchanged.

However, after one pattern area is exposed, both the mask stage and the wafer stage are temporarily stopped. Thereafter, the next pattern area is exposed by scanning the stages in the opposite direction. To increase the mask and wafer scanning velocities, therefore, is to prolong the time required to accelerate each scanning velocity to the above scanning velocity and the time required to decelerate each of the mask and wafer scanning velocities to 0. At a given scanning velocity or higher, since the time required to scan a pattern area to be exposed shortens because of an increase in scanning velocity. However, the time required to accelerate each of the mask and wafer scanning velocities to the scanning velocity in the pattern area to be exposed and the time required to

decelerate each scanning velocity to 0 is prolonged
more than the time shortened. As a result, the total
time required to start driving a mask and wafer, reach
the scanning velocity in a pattern area to be exposed,

5   and complete driving operation of the mask and wafer
may be prolonged as the scanning velocity is increased,
resulting in a reduction in throughput.

SUMMARY OF THE INVENTION

10   The present invention has been made in
consideration of the above points, and has as its
object to provide an exposure apparatus which has a
scanning velocity determination means to maximize the
throughput.

15   In order to achieve the above object, according
to the present invention, there is provided a scanning
exposure apparatus comprising: a master stage for
scanning a master, a substrate stage for scanning a
substrate, transfer means for supplying/recovering the

20   substrate to/from the substrate stage, and positioning
means for relatively positioning the substrate and the
master, scanning velocity determination means for
determining a scanning velocity so as to maximize the
number of substrates that can be exposed per unit time,

25   i.e., a throughput.

The scanning velocity determining means
determines, as a scanning velocity in actual exposure

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operation, a lowest one of

a maximum scanning velocity determined from
apparatus performance: Vmax,

a scanning velocity determined from an exposure
illuminance and a required exposure amount: Vd, and

a scanning velocity at which the number of
substrates that can be processed per unit time is
maximized, which is determined from the transfer
pattern size, a layout of the transfer pattern on the
substrate, the transfer means, the master scanning
means, the substrate stage scanning means, and the
positioning means: Vt.

If the light source is a light source for
emitting pulsed light, the scanning velocity
determining means determines, as a scanning velocity in
actual exposure operation, a lowest one of

a maximum scanning velocity determined from
apparatus performance: Vmax,

a scanning velocity determined from an exposure
illuminance and a required exposure amount: Vd,

a scanning velocity determined from the minimum
number of pulses which is required for integration to
ensure a uniform exposure amount: Vp, and

a scanning velocity at which the number of
substrates that can be processed per unit time is
maximized, which is determined from the transfer
pattern size, a layout of the transfer pattern on the

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substrate, the transfer means, the master scanning means, the substrate stage scanning means, and the positioning means: Vt.

More specifically, the scanning velocity Vp satisfies

$$Vp = Ws/Pmin \times fmax$$

where Ws is a width of an illumination area, on the substrate in a non-scanning direction, which illuminates part of the transfer pattern, fmax is a maximum frequency of pulsed light emitted from the light source, and Pmin is the minimum number of pulses required for integration to ensure a uniform exposure amount on the substrate.

The scanning velocity Vd satisfies

$$Vd = Imax/D \times Ws$$

where Imax is a maximum exposure illuminance, and D is a required exposure amount determined by a photosensitive material.

The scanning velocity Vt is calculated by simulation to maximize the number of substrates that can be processed per unit time on the basis of the transfer pattern size, a layout of the transfer pattern on the substrate, and conditions in the master scanning means, the substrate stage scanning means, the transfer means, and the positioning means or satisfies

$$Vscan.min = \sqrt{\{L \times \alpha accel \times \alpha decel/(\alpha accel + \alpha decel)\}}$$

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$$Vt = g(Vscan.min)$$

where αaccel is an average acceleration with which an increase in scanning velocity from 0 to Vt is achieved, αdecel with which a decrease in scanning velocity from

5   Vt to 0 is achieved, L is a length on the substrate which is scanned at a constant velocity in one scanning operation, and g() is an arbitrary function.

In this case, since the length L changes for each transfer pattern in accordance with the transfer

10   pattern size and the layout of the transfer pattern on the substrate, the optimal value of Vt is determined to be changed for each transfer pattern. In addition, the scanning velocity Vt may be changed for each shot area to be exposed in accordance with the length that is

15   scanned at a constant velocity in one scanning operation.

By determining a scanning velocity in this manner, a maximum throughput can always be obtained, and hence the productivity of devices can be increased.

20   Other features and advantages of the present invention will be apparent from the following description taken in conjunction with the accompanying drawings, in which like reference characters designate the same or similar parts throughout the figures

25   thereof.

BRIEF DESCRIPTION OF THE DRAWINGS

- 10 -

Fig. 1 is a schematic view showing the arrangement of an exposure apparatus according to an embodiment of the present invention;

Fig. 2 is a view for explaining a shot area and 5 exposure slit in scanning exposure;

Fig. 3A is a view for explaining a shot layout on a wafer and an exposure order in an exposure apparatus according to the first embodiment of the present invention;

10 Fig. 3B is a view for explaining a shot layout on a wafer and an exposure order in an exposure apparatus according to the second embodiment of the present invention;

Fig. 4 is a chart showing the relationship 15 between the wafer stage velocity and the time in scanning exposure according to the first embodiment of the present invention;

Fig. 5 is a chart showing the relationship between the wafer stage velocity and the time in 20 scanning exposure according to the second embodiment of the present invention;

Fig. 6A is a graph for explaining a stage acceleration pattern;

Fig. 6B is a graph for explaining a stage 25 acceleration pattern;

Fig. 7A is a graph showing the relationship between the scanning velocity and the throughput;

Fig. 7B is a graph showing the relationship between the scanning velocity and the time period from the start of scanning of a shot area to the end of scanning;

5   Fig. 7C is a graph showing the relationship between the scanning velocity and the time period from the start of scanning of a shot area to the end of scanning;

Fig. 8 is a view showing the concept of a

10   semiconductor device production system according to the present invention when viewed from a given angle;

Fig. 9 is a view showing the concept of the semiconductor device production system according to the present invention when viewed from another given angle;

15   Fig. 10 is a view showing an example of a user interface in the exposure apparatus according to the present invention;

Fig. 11 is a flow chart showing the flow of a semiconductor device manufacturing process according to

20   the present invention; and

Fig. 12 is a flow chart showing a wafer process in Fig. 11 which is performed by the exposure apparatus according to an embodiment of the present invention.

25   DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS
(First Embodiment)

Fig. 1 is a schematic view showing an exposure

apparatus according to an embodiment of the present

invention. In this case, a pulse laser such as an

excimer laser is used as an exposure light source. A

light beam L emitted from a light source 1 formed by a

5   pulse laser such as an excimer laser is shaped into a

predetermined shape by a beam shaping optical system 2

and incident on an optical integrator 3. The optical

integrator 3 is formed by a flyeye lens constituted by

a plurality of microlenses, and has a plurality of

10   secondary sources near its light exit surface. Light

beams from the secondary sources near the light exit

surface of the optical integrator 3 illuminate, through

a condenser lens 4, a movable slit 6 whose aperture

shape can be changed. Reference numeral 14 denotes an

15   exposure amount detector A for detecting the amount of

part of illumination light split by a half mirror 5 and

outputting the resultant signal to an exposure amount

computing unit 102.

The light beams illuminating the movable slit 6

20   illuminate part of a circuit pattern, in the form of a

slit, which is formed on a mask 10 serving as a master

held on a mask stage 9, through an imaging lens 7 and

mirror 8.

With a light beam in the form of a slit, which

25   has passed through the mask 10, the circuit pattern on

the mask 10 is reduced/projected, through a projection

lens 11, on a wafer 12 having a surface coated with a

resist as a photosensitive material. The wafer 12
serving as a substrate to be exposed is held on a wafer
stage 13 that can be driven in the X, Y, and Z
directions and tilt direction. An exposure amount
5   detector B (15) is mounted on the wafer stage 13 to
monitor an exposure amount through the projection lens
11. At an early stage in an exposure process, the
correlation between the amount of exposure light that
has passed through the projection lens 11 and detected
10   by the exposure amount detector B (15) on the wafer
stage 13 and the amount of exposure light that is
detected by the exposure amount detector A (14) is
obtained in advance, and actual exposure operation is
controlled on the basis of the exposure amount detected
15   by the exposure amount detector A (14).

Reference numeral 101 denotes a laser control
system for controlling the output energy and
oscillation frequency of the light source 1 by
outputting a trigger signal and charging voltage signal
20   in accordance with a desired set exposure amount. This
apparatus includes a light attenuation means (not
shown) and can adjust the amount of light from the
light source 1.

The positions of the mask stage 9 and wafer stage
25   13 are respectively measured by interferometers 16 and
17, and a mask stage control system 104 and wafer stage
control system 105 respectively control the mask stage

9 and wafer stage 13 in accordance with an instruction

from a main control system 103 to accurately scan the

light beam that illuminates part of the mask pattern in

the form of a slit in opposite directions at

5   predetermined velocities at a ratio equal to a

projection magnification β of the projection lens 11.

In this manner, as shown in Fig. 2, the slit-like light

beam continuously scans/exposes an entire exposure area

(to be referred to as a "shot area" hereinafter) on the

10 wafer 12 exposed to a mask pattern, thus

exposing/transferring the entire mask pattern onto he

wafer 12. Referring to Fig. 2, each hatched portion e

is a portion of the wafer 12 that is actually exposed,

and each dotted portion s indicates the slit. The

15 movement of a light beam between the respective shot

areas on the wafer 12 is performed by XY-driving the

wafer stage 13.

After all desired shot areas on the wafer 12 are

completely exposed, the wafer 12 is transferred outside

20 the exposure apparatus from the wafer stage 13 through

a wafer recovery/transfer system 18. At the same time,

the next wafer is supplied onto the wafer stage 13 via

a wafer supply/transfer system 19 (identical to the

wafer recovery/transfer system 18 in Fig. 1 for the

25 sake of illustrative convenience). Thereafter, an

alignment system (not shown) performs positioning with

the pattern that has already been formed on the wafer

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12. According to one alignment method, the positions of alignment marks mainly formed on peripheral portions of a plurality of shot areas selected on the wafer 12 to obtain rotation, expansion/contraction, and shift

5   offsets and the like of the wafer 12, thereby positioning all shot areas on the wafer 12. Coarse alignment for the detection of alignment marks is sometimes performed before this fine alignment. After each shot area is positioned in this manner, the above

10   exposure operation is repeatedly performed.

A procedure for obtaining a scanning velocity at which a maximum throughput can be obtained will be described next.

A "throughput" will indicate the number of wafers

15   exposed by the apparatus per unit time under a proper exposure under conditions for proper exposure hereinafter. The "number of wafers processed" to be described later indicates the number of wafers processed by the apparatus per unit time regardless of

20   whether conditions for proper exposure are set or not.

First, in a scanning exposure apparatus, a maximum scanning velocity Vmax is substantially determined, which is determined from the performance of a system control system, including structure and

25   mechanical performance, in order to attain desired imaging performance and overlay accuracy. That is, if scanning exposure is performed at this velocity or

higher, a desired fine integrated circuit pattern cannot be formed or a desired overlay accuracy cannot be ensured. Therefore, a scanning velocity V must satisfy

5     $V \leqq V\text{max}$ ... (6)

Second, a proper exposure amount D is determined depending on the type of resist to be used and an exposure process to properly form a circuit pattern on the mask 10. In scanning exposure, exposure amount 10 control is performed to set the exposure amount at each point on the wafer 12 to the above proper exposure amount D. Letting Imax be the maximum exposure illuminance in scanning exposure and Ws be the slit width on the wafer 12 in the scanning direction, the 15 scanning velocity V must satisfy

$Vd = I\text{max}/D \times Ws$ ... (7)

$V \leqq Vd$ ... (8)

If the scanning velocity V must be set to be lower than Vd, the illuminance must be decreased. As 20 methods of decreasing the illuminance, for example, the following methods are available: a method of decreasing the illuminance by decreasing the energy per laser pulse; a method of decreasing the illuminance by attenuating pulsed light by using a light attenuation 25 means such as an ND filter set on an optical path; a method of decreasing the illuminance by decreasing the pulse oscillation frequency; and a combination of these

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methods.

Third, with a reduction in the size of an IC pattern, the illuminance evenness of exposure light is required for the performance of the exposure apparatus. However, pulsed light from a pulsed light source such as an excimer laser varies in energy for each pulse. For this reason, exposure must be performed with the number of pulses equal to or more than a predetermined pulse count Pmin at each point on a wafer to integrate pulse energy so as to maintain predetermined illuminance evenness.

Letting fmax be the maximum oscillation frequency of the exposure light source, therefore, the scanning velocity V must satisfy

$$Vp = Ws/Pmin \times fmax \qquad \ldots(9)$$

$$V \leqq Vp \qquad \ldots(10)$$

Fourth, without any consideration given to the first to third conditions, letting Vt be the maximum scanning velocity at which the number of wafers that can be processed by the apparatus per unit time (to be referred to as "the number of wafers processed" hereinafter) is maximized, in order to prevent a decrease in throughput, the scanning velocity V must satisfy

$$V \leqq Vt \qquad \ldots(11)$$

The above scanning velocity Vt will be described next.

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Letting T (sec) be the time required to process one wafer, the number N of wafers processed per unit time is defined by

$$N = 3600/T \qquad \dots(12)$$

An example of a breakdown of the time T required to process one wafer can be expressed as follows. Letting Tload (sec) be the time required to supply a wafer, Talign (sec) be the time required for alignment, Tscan (sec) be the time required for scanning exposure, and Tunload (sec) be the time required to recover the wafer, then the time T is defined by

$$T = Tload + Talign + Tscan + Tunload \qquad \dots(13)$$

Tload, Talign, Tscan, and Tunload are the functions of the wafer stage velocity and acceleration, shot size, shot layout, and the like and can be expressed as follows:

$$Tload = Tload (Vsl, \alpha sl,...)$$

$$Talign = Talign (Vsa, \alpha sa, Layout\_align, Vscan, \alpha scan,...)$$

$$Tscan = Tscn (Vscan, \alpha scan, Vstep, \alpha step, layout\_shot, Size\_shot,...)$$

$$Tunload = Tunload (Vsul, \alpha sul, Layout\_shot, Vscan, \alpha scan,...)$$

$$T = Tload + Talign + Tscan + Tunload$$

where

Vsl (mm/sec): wafer stage velocity in supplying wafer

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α sl (mm/sec^2): wafer stage acceleration in supplying wafer

Vsa (mm/sec): wafer stage velocity during alignment

α sa (mm/sec^2): wafer stage acceleration during alignment

Layout_align: layout at alignment mark measurement position

Vscan (mm/sec): wafer stage/mask stage velocity during scanning exposure

α scan (mm/sec^2): wafer stage/mask stage acceleration during scanning exposure

Vstep (mm/sec): wafer stage velocity during movement of shot area

α step (mm/sec^2): wafer stage acceleration during movement of shot area

Layout_shot: shot layout

Size_shot: size of shot area

Vul (mm/sec): wafer stage velocity in wafer recovery

α ul (mm/sec^2): wafer stage acceleration in wafer recovery

For the sake of simplicity, the communication time and computation time required for software to control driving of the wafer stage 13, mask stage 9, and the like, alignment mark measurement time, and the

like are omitted, and each velocity and acceleration are written without discrimination between the wafer stage 13 and the mask stage 9, and between scanning direction, non-scanning direction, accelerating

5   operation, decelerating operation, and the like.

The reason why Talign is a function of the scanning velocity Vscan and scanning acceleration α scan is that movement from the final shot in alignment to the scanning start position for the first exposure

10   shot is included. The scanning start position is a position spaced apart from a shot area to be exposed by an acceleration distance required to reach a desired scanning velocity. Scanning of the wafer stage 13 is started from this position. If, therefore, the

15   scanning acceleration α scan remains the same, the acceleration distance required to reach the scanning velocity Vscan decreases as the scanning acceleration Vscan decreases, and vice versa. Since the moving distance from the alignment final measurement position

20   to the first exposure shot start position changes, the moving time also changes. For this reason, Talign is a function of the scanning velocity Vscan and scanning acceleration α scan. Likewise, the reason why Tunload is a function of the scanning velocity Vscan and

25   scanning acceleration α scan is that movement from the scanning exposure end position in the final shot to the wafer recovery position is included.

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As the wafer stage velocity and acceleration in supplying a wafer, the maximum values in terms of the capacity of the apparatus are used to minimize the time Tload required to supply the wafer. The time Tload

5 remains constant regardless of the scanning velocity Vscan. As the wafer stage velocity and acceleration during alignment, the maximum values in terms of the capacity of the apparatus are used to minimize the time Talign required for alignment. Strictly speaking,

10 although Talign is a function of the scanning velocity Vscan, since alignment is performed by sequentially measuring alignment marks in a plurality of shot areas, the difference between the scanning velocity Vscan and the scanning acceleration αscan has little influence

15 on the time Talign. Hence, this time can substantially be regarded as a constant value regardless of the scanning velocity Vscan. In addition, the time Tunload required for wafer recovery is also a function of the scanning velocity Vscan. Likewise, this time can

20 substantially be regarded as a constant value regardless of Vscan.

Therefore, the number N of wafers processed per unit time is substantially determined by the time Tscan required for scanning exposure.

25 The relationship between the time required for scanning exposure, the wafer stage velocity, and the mask stage velocity will be described next with

reference to Figs. 3A and 4.

Fig. 3A schematically shows the layout of shot areas. Each arrow indicates the scanning route of the slit. The exposure order is S → A → B → C → .... The slit is relatively scanned upward in a shot area A and downward in a shot area B.

Fig. 4 shows an example of the relationship between the time, the wafer stage velocity, and the mask stage velocity. In this case, the scanning direction coincides with the Y-axis, and the non-scanning direction coincides with the X-axis. Referring to Fig. 4, the upper, intermediate, and lower charts schematically show the relationships between the velocity of the wafer stage 13 in the Y-axis direction and the time, between the velocity of the wafer stage 13 in the X-axis direction and the time, and between the velocity of the mask stage 9 in the Y-axis direction and the time, respectively.

The wafer stage 13 starts to accelerate from a velocity of 0 at time t_A0 with an average acceleration $\alpha accel$, and reaches the scanning velocity Vscan at time t_A1. Then, after a lapse of a time tsettle required to settle the synchronization error between the wafer stage 13 and the mask stage 9 within a predetermined precision range, exposure is started at time t_A2. The distance that the wafer stage 13 travels until this exposure start time is considered in

advance as an approach distance to set the position of the wafer stage 13 at time t_A0. As shown in Fig. 2, a distance L required for scanning an entire shot area at a constant velocity is the sum of a length Ly of the shot area in the scanning direction and the length Ws of the slit in the scanning direction. The exposure time is therefore given by $L/Vscan = (Ly + Ws)/Vscan$. The exposure ends at time t_A3. The wafer stage 13 then starts decelerating with an average acceleration $\alpha decel$, and reaches the velocity 0 at time t_A4. Thereafter, the wafer stage 13 starts driving toward an approach start position for exposure of the shot area B. At time t_A6 ($= t\_B0$), this driving operation ends.

With regard to the non-scanning direction, the wafer stage 13 starts driving by a length Lx of the shot area in the non-scanning direction at time t_A3 at which the exposure is terminated. At time t_A5, this driving operation ends. For the sake of simplicity, assume that time t_A5 is earlier than an exposure start time t_B2 for the shot area B. The mask stage 9 also starts decelerating at time t_A0, like the wafer stage 13, and reaches the velocity 0 at time t_A4. However, a scanning velocity Vscan (R) of the mask stage 9 differs from that of the wafer stage 13 by the projection magnification β.

Similarly, it takes the time period between time t_B0 and time t_B6 to expose the shot area B; and the

time period between time t_C0 and time t_C6 to expose a shot area C.

In this case, the step times in the scanning direction between t_A4 and t_A6, t_B4 and t_B6, and

5   t_C4 and t_C6, and the step times in the non-scanning direction between t_A3 and t_A5, and t_B3 and t_B5 are determined regardless of the scanning velocity Vscan as long as a shot layout and scanning order are determined.

The time period between scanning start time t_A0

10   and scanning end time t_A4 is expressed as follows:

$$t\_A1 - t\_A0 = Vscan/\alpha accel$$

$$t\_A2 - t\_A0 = Vscan/\alpha accel + tsettle$$

$$t\_A3 - t\_A0 = Vscan/\alpha accel + tsettle + L/Vscan$$

$$t\_A4 - t\_A0 = Vscan/\alpha accel + tsettle + L/Vscan$$

15   $$+ Vscan/\alpha decel$$

Therefore, a time period tscan(Vscan) from the start of scanning of a shot area to the end of scanning is given by

$$tscan(Vscan) = Vscan/\alpha accel + tsettle + L/Vscan$$

20   $$+ Vscan/\alpha decel \qquad \ldots(14)$$

Since the accelerations $\alpha accel$ and $\alpha decel$ take the maximum values in terms of the capacity of the apparatus to shorten the acceleration and deceleration times, these values can be regarded as constant values.

25   Differential of second order taking Vscan as a variable is expressed as follows:

$$\partial^2 t/\partial V^2 scan = 2 \times L/V^3 \geq 0$$

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Therefore, tscan(Vscan) is a function exhibiting a characteristic in an inverted convex form, and takes a minimum value. A scanning velocity Vscan.min that minimizes the time period from the start of scanning of a shot area to the end of scanning is given by

$$Vscan.min = \sqrt{\{L \times \alpha accel \times \alpha decel/(\alpha accel + \alpha decel)\}}$$

Letting Tstep be the sum of the step times in the scanning direction between t_A4 and t_A6, t_B4 and t_B6, t_C4 and t_C6,..., and Nshot be the number of shot areas per wafer, the time Tscan required for scanning exposure is given by

$$Tscan = Tstep + Nshot \times tscan(Vscan)$$

The time T required to process one wafer is given by

$$T = Tload + Talign + Tscan + Tunload$$
$$= Tload + Talign + \{Tstep + Nshot \times tscan(Vscan)\} + Tunload \qquad \ldots(15)$$

As described above so far, all the times except for Tscan(Vscan) need not be regarded as functions of Vscan, and are constant values, and hence the time T required to process one wafer at the scanning velocity Vscan.min takes a minimum value. That is, the maximum number of wafers processed is set.

Therefore, the scanning velocity Vt at which the maximum number of wafers processed is set is expressed as

$$Vt = Vscan.min \qquad \ldots(16)$$

As described above, since the scanning velocity V must satisfy equations (6), (8), (10, and (11), the scanning velocity V at which the throughput is substantially maximized is given by

$$V = min(Vmax, \ Vd, \ Vp, \ Vt)$$

where min() is a function for obtaining a minimum value.

According to equations (12), (14), and (15), the relationship between the scanning velocity and the throughput exhibits the form shown in Fig. 7A. Assume that Vmax, Vd, Vp, and Vt have a relationship like that shown in Fig. 7A (Vt < Vp < Vmax < Vd). In this case, if the conventional method without any consideration given to the scanning velocity Vt at which the number of wafers processed is maximized is used, exposure is performed at the scanning velocity Vp which is high and at which the synchronization error tends to become large, and the throughput at this time become TP_{vp}. If the method of the present invention is used, exposure is performed at the scanning velocity Vt which is lower than Vp and advantageous in terms of synchronization precision, and the throughput at this time is Tp_{vt}.

As is obvious from Fig. 7A, since $TP_{vp} \leqq TP_{vt}$, the productivity can be improved.

(Second Embodiment)

The second embodiment of the present invention will be described. In this case, Figs. 3B and 5 show

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the relationship between the shot layout on a wafer,
the wafer stage velocity, and the mask stage velocity.

When a slit-like light beam moves from a shot
area B to a shot area C, the wafer stage starts
5   decelerating at exposure end time t_B3 in Fig. 4. In
this case, however, even after the exposure ends at
time t_B3, the wafer stage moves at the same velocity
as that in the exposure operation, and starts
decelerating at time t_B4 to decrease the velocity to 0
10   at an approach start position for exposure of the shot
area C. The wafer stage reaches the approach start
position for exposure of the shot area C at time t_B6
(t_C0).

In this case, a length L that the wafer stage
15   scans at a constant velocity in one scanning operation
is expressed by L > Ly + Ws instead of L = Ly + Ws.
The length L varies for each shot area, and a scanning
velocity Vscan.minB in the shot area B is higher than a
scanning velocity Vscan.minA that minimizes the time
20   period from the start of scanning of the shot area A to
the end of scanning.

In practice, a scanning velocity must be so
determined as to satisfy equations (6), (8), and (10)
as well. For this reason, a scanning velocity V_A that
25   minimizes the time period from the start of scanning of
the shot area A to the end of scanning while satisfying
equations (6), (8), and (10) is given by

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$$V\_A = min \, (Vmax, \; Vd, \; Vp, \; Vscan.minA)$$

In the shot area B,

$$v\_B = min \, (Vmax, \; Vd, \; Vp, \; Vscan.minB)$$

Assume that Fig. 7B shows the relationship

5   between the scanning velocity and a time t(Vscan) from
the start of scanning of the shot area A to the end of
scanning, and Fig. 7C shows the relationship between
the scanning velocity and a time t(Vscan) from the
start of scanning of the shot area B to the end of

10   scanning. In this case, the above scanning velocities
V_A and V_B are respectively given by

$$V\_A = Vscan.minA$$

$$V\_B = Vp$$

and hence differ from each other.

15   If, therefore, the scanning velocity is changed
in accordance with the length L that is scanned at a
constant velocity in one scanning operation for each
shot area, the time required for each shot area can be
minimized. As a consequence, the throughput can be

20   maximized.

In the case described above, the slit-like light
beam moves from a given shot area to another shot area,
which are equal in size but differ in their positions
in the Y direction. However, the same applies to a

25   case where shot areas have different sizes within a
wafer, because the length L that is scanned at a
constant velocity varies.

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In the above case, for example, α accel, α decel, and tsettle are set to constant values within a wafer, and exposure is performed from the upper right shot area on the wafer in the order of S → A → B → C → ....

In addition, movement end times t_A5 and t_B5 in the non-scanning direction are set to be earlier than exposure start times t_B2 and t_C2 for the next shot area to prevent movement in the non-scanning direction from influencing the time Tscan required for scanning exposure.

Assume that a different exposure order is set, movement in the non-scanning direction or movement of the mask stage influences the time Tscan required for scanning exposure, and α accel, α decel, tsettle, Vstep, and the like vary within a wafer. In this case, if accelerations are determined in accordance with actual stage control in consideration of smooth velocity changes at P1 and P2 as shown in Fig. 6B instead of assuming the average accelerations α accel and α decel that abruptly change at P1 and P2 as shown in Fig. 6A, and the accelerations themselves are functions of a scanning velocity, the scanning velocity Vt at which the number of wafers processed is maximized is not necessarily given by equation (16).

In such a case, if representative values α accel and α decel within a wafer are used, a relationship similar to that represented by equation (16) is

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established. Strictly speaking, the scanning velocity

Vt at which the number of wafers processed is maximized

can be expressed as a function of Vscan.min as follows:

$$Vt = g(Vscan.min) \qquad \ldots (17)$$

5   where g() is an arbitrary function.

The function g() may be actually obtained by one

of the following methods. For example, scanning

velocities Vt.1, Vt.2, Vt.3,... at which the number of

wafers processed is maximized are actually obtained

10   under several conditions including the length L that is

scanned at a constant velocity in one scanning

operation, accelerations, and the like, and these

velocities are approximated as a polynomial of

Vscan.min. Alternatively, scanning velocities are

15   determined as constant multiples of Vscan.min for the

respective conditions and approximated in the form of a

table.

According to another method, if an

acceleration/deceleration pattern like that shown in

20   Fig. 6A or 6B, including an exposure order and

variations within a wafer, is known, a time T required

to process one wafer can be calculated. In this case,

a time Talign required for alignment and a time Tunload

required for wafer recovery, which are regarded as

25   constant values in the above description, may be

accurately calculated as functions of a scanning

velocity Vscan. If the time T required to process one

wafer is calculated in this manner, a scanning velocity
Vt at which the number of wafers processed is maximized
can be obtained by numerical calculation.

The above embodiments have exemplified the case
where a pulse laser is used. Even if, however, a
continuous light source like a mercury lamp is used,
the scanning velocity V that maximizes the throughput
can be obtained by the equation given below in the same
manner as described above except that there is no need
to consider a velocity Vp controlled with the minimum
number of exposure pulses.

$$V = \min(Vmax, Vd, Vt)$$

The scanning velocity V for each shot in each
shot area in the exposure apparatus according to each
embodiment described above is displayed on a display
(not shown).

(Embodiment of Semiconductor Production System)

A production system for producing a semiconductor
device (semiconductor chip such as an IC or LSI, liquid
crystal panel, CCD, thin-film magnetic head,
micromachine, or the like) by using the exposure
apparatus according to the present invention will be
exemplified. A trouble remedy or periodic maintenance
of a manufacturing apparatus installed in a
semiconductor manufacturing factory, or maintenance
service such as software distribution is performed by
using a computer network outside the manufacturing

factory.

Fig. 8 shows the overall system cut out at a given angle. In Fig. 8, reference numeral 1101 denotes a business office of a vendor (apparatus supply manufacturer) which provides a semiconductor device manufacturing apparatus. Assumed examples of the manufacturing apparatus are semiconductor manufacturing apparatuses for various processes used in a semiconductor manufacturing factory, such as pre-process apparatuses (lithography apparatus including an exposure apparatus, resist processing apparatus, and etching apparatus, annealing apparatus, film formation apparatus, planarization apparatus, and the like) and post-process apparatuses (assembly apparatus, inspection apparatus, and the like). The business office 1101 comprises a host management system 1108 for providing a maintenance database for the manufacturing apparatus, a plurality of operation terminal computers 1110, and a LAN (Local Area Network) 1109 which connects the host management system 1108 and computers 1110 to build an intranet. The host management system 1108 has a gateway for connecting the LAN 1109 to Internet 1105 as an external network of the business office, and a security function for limiting external accesses.

Reference numerals 1102 to 1104 denote manufacturing factories of the semiconductor

manufacturer as users of manufacturing apparatuses.
The manufacturing factories 1102 to 1104 may belong to
different manufacturers or the same manufacturer
(pre-process factory, post-process factory, and the

5   like). Each of the factories 1102 to 1104 is equipped
with a plurality of manufacturing apparatuses 1106, a
LAN (Local Area Network) 1111 which connects these
apparatuses 1106 to construct an intranet, and a host
management system 1107 serving as a monitoring

10   apparatus for monitoring the operation status of each
manufacturing apparatus 1106. The host management
system 1107 in each of the factories 1102 to 1104 has a
gateway for connecting the LAN 1111 in the factory to
the Internet 1105 as an external network of the factory.

15   Each factory can access the host management system 1108
of the vendor 1101 from the LAN 1111 via the Internet
1105. The security function of the host management
system 1108 authorizes access of only a limited user.
More specifically, the factory notifies the vendor via

20   the Internet 1105 of status information (e.g., the
symptom of a manufacturing apparatus in trouble)
representing the operation status of each manufacturing
apparatus 1106, and receives response information (e.g.,
information designating a remedy against the trouble,

25   or remedy software or data) corresponding to the
notification, or maintenance information such as the
latest software or help information. Data

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communication between the factories 1102 to 1104 and
the vendor 1101 and data communication via the LAN 1111
in each factory adopt a communication protocol (TCP/IP)
generally used in the Internet. Instead of using the

5   Internet as an external network of the factory, a
dedicated network (e.g., ISDN) having high security
which inhibits access of a third party can be adopted.
Also the user may construct a database in addition to
the one provided by the vendor and set the database on

10   an external network, and the host management system may
authorize access to the database from a plurality of
user factories.

       Fig. 9 is a view showing the concept of the
overall system of this embodiment that is cut out at a

15   different angle from Fig. 8. In the above example, a
plurality of user factories having manufacturing
apparatuses and the management system of the
manufacturing apparatus vendor are connected via an
external network, and production management of each

20   factory or information of at least one manufacturing
apparatus is communicated via the external network. In
the example of Fig. 9, a factory having manufacturing
apparatuses of a plurality of vendors and the
management systems of the vendors for these

25   manufacturing apparatuses are connected via the
external network of the factory, and maintenance
information of each manufacturing apparatus is

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communicated. In Fig. 9, reference numeral 1201 denotes a manufacturing factory of a manufacturing apparatus user (semiconductor device manufacturer) where manufacturing apparatuses for various processes, e.g., an exposure apparatus 1202, resist processing apparatus 1203, and film formation apparatus 1204 are installed in the manufacturing line of the factory. Fig. 9 shows only one manufacturing factory 1201, but a plurality of factories are networked in practice. The respective apparatuses in the factory are connected to a LAN 1206 to build an intranet, and a host management system 1205 manages the operation of the manufacturing line.

The business offices of vendors (apparatus supply manufacturers) such as an exposure apparatus manufacturer 1210, resist processing apparatus manufacturer 1220, and film formation apparatus manufacturer 1230 comprise host management systems 1211, 1221, and 1231 for executing remote maintenance for the supplied apparatuses. Each host management system has a maintenance database and a gateway for an external network, as described above. The host management system 1205 for managing the apparatuses in the manufacturing factory of the user, and the management systems 1211, 1221, and 1231 of the vendors for the respective apparatuses are connected via the Internet or dedicated network serving as an external network

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1200. If a trouble occurs in any one of a series of
manufacturing apparatuses along the manufacturing line
in this system, the operation of the manufacturing line
stops. This trouble can be quickly solved by remote

5   maintenance from the vendor of the apparatus in trouble
via the Internet 1200. This can minimize the stop of
the manufacturing line.

Each manufacturing apparatus in the semiconductor
manufacturing factory comprises a display, a network

10   interface, and a computer for executing network access
software and apparatus operating software which are
stored in a storage device. The storage device is a
built-in memory, hard disk, or network file server.
The network access software includes a dedicated or

15   general-purpose web browser, and provides a user
interface having a window as shown in Fig. 10 on the
display. While referring to this window, the operator
who manages manufacturing apparatuses in each factory
inputs, in input items on the windows, pieces of

20   information such as the type of manufacturing apparatus
1401, serial number 1402, object of trouble 1403,
occurrence date 1404, degree of urgency 1405, symptom
1406, remedy 1407, and progress 1408. The pieces of
input information are transmitted to the maintenance

25   database via the Internet, and appropriate maintenance
information is sent back from the maintenance database
and displayed on the display. The user interface

provided by the web browser realizes hyperlink

functions 1410 to 1412, as shown in Fig. 10. This

allows the operator to access detailed information of

each item, receive the latest-version software to be

5   used for a manufacturing apparatus from a software

library provided by a vendor, and receive an operation

guide (help information) as a reference for the

operator in the factory. Maintenance information

provided by the maintenance database also includes

10   information concerning the present invention described

above. The software library also provides the latest

software for implementing the present invention.

A semiconductor device manufacturing process

using the above-described production system will be

15   explained. Fig. 11 shows the flow of the whole

manufacturing process of the semiconductor device. In

step 1 (circuit design), a semiconductor device circuit

is designed. In step 2 (mask formation), a mask having

the designed circuit pattern is formed. In step 3

20   (wafer manufacture), a wafer is manufactured by using a

material such as silicon. In step 4 (wafer process)

called a pre-process, an actual circuit is formed on

the wafer by lithography using a prepared mask and the

wafer. Step 5 (assembly) called a post-process is the

25   step of forming a semiconductor chip by using the wafer

manufactured in step 4, and includes an assembly

process (dicing and bonding) and packaging process

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(chip encapsulation). In step 6 (inspection),
inspections such as the operation confirmation test and
durability test of the semiconductor device
manufactured in step 5 are conducted. After these

5   steps, the semiconductor device is completed and
shipped (step 7). For example, the pre-process and
post-process are performed in separate dedicated
factories, and maintenance is done for each of the
factories by the above-described remote maintenance

10   system. Information for production management and
apparatus maintenance is communicated between the
pre-process factory and the post-process factory via
the Internet or dedicated network.

     Fig. 12 shows the detailed flow of the wafer

15   process. In step 11 (oxidation), the wafer surface is
oxidized. In step 12 (CVD), an insulating film is
formed on the wafer surface. In step 13 (electrode
formation), an electrode is formed on the wafer by
vapor deposition. In step 14 (ion implantation), ions

20   are implanted in the wafer. In step 15 (resist
processing), a photosensitive agent is applied to the
wafer. In step 16 (exposure), the exposure apparatus
described above exposes the wafer to the circuit
pattern of a mask. In step 17 (developing), the

25   exposed wafer is developed. In step 18 (etching), the
resist is etched except for the developed resist image.
In step 19 (resist removal), an unnecessary resist

after etching is removed. These steps are repeated to form multiple circuit patterns on the wafer. A manufacturing apparatus used in each step undergoes maintenance by the remote maintenance system, which

5   prevents a trouble in advance. Even if a trouble occurs, the manufacturing apparatus can be quickly recovered. The productivity of the semiconductor device can be increased in comparison with the prior art.

10   According to the present invention, there are provided an exposure apparatus which can perform scanning exposure with a maximum possible throughput by determining a scanning velocity in consideration of the maximum scanning velocity determined from the

15   performance of a stage control system, including structural and mechanical performance, the scanning velocity determined from an exposure amount, the scanning velocity determined from the minimum number of exposure pulses, and the scanning velocity that

20   maximizes the number of substrates such as wafers to be processed, and a device manufacturing method using the exposure apparatus. This makes it possible to increase the throughput while satisfying various constraint conditions.

25   In addition, the scanning velocity Vt at which the number of substrates processed per unit time is maximized, which is determined from a transfer pattern

size, the layout on the transfer pattern, a transfer means, a master scanning means, a substrate scanning means, and a positioning means is calculated in advance by simulation based on a transfer pattern size, the

5   layout on the transfer pattern, and conditions in the transfer means, master scanning means, substrate stage scanning means, and positioning means, or is changed for each transfer pattern in accordance with a transfer pattern size and the layout of the transfer pattern on

10   a substrate. The throughput can be further increased by changing the scanning velocity for each shot area to be exposed in accordance with the length that is scanned at a constant velocity in one scanning operation.

15   As many apparently widely different embodiments of the present invention can be made without departing from the spirit and scope thereof, it is to be understood that the invention is not limited to the specific embodiments thereof except as defined in the

20   appended claims.